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(54) Title: APPARATUS COMPRISING A PNEUMOACOUSTIC ATOMIZER

(57) Abstract: A fire-suppression apparatus that includes a pneumoacoustic atomizer for delivering a mist of liquid (e.g., water) in the form of droplets having a size in the range of about 50 to 90 microns. The mist is suspended in a fire-suppressing gas such as nitrogen. Gas is supplied to the pneumoacoustic atomizer from a system that, in some embodiments, includes both bottles and a gas generator. To minimize consumption of fire-suppressing materials, the fire-suppression apparatus can be operated in a pulsed mode wherein delivery of fire-suppressing materials is interrupted unless a sensor detects a fire re-flash. In some variations, the pneumoacoustic atomizer operates at very low pressures, as is desirable for use in aircraft.

APPARATUS COMPRISING A PNEUMOACOUSTIC ATOMIZER

Field of the Invention

The present invention relates to atomizers and, more particularly, to the use of atomizers in automated fire-suppression systems.

Background of the Invention

Many existing fire-suppression systems use fluorocarbons (*e.g.*, bromotrifluoromethane, dibromotetrafluoroethane, bromochlorodifluoromethane, *etc.*), such as are commonly sold under the trademark Halon. The continued use of fluorocarbons has, however, been discouraged, restricted or banned on a worldwide basis due to environmental concerns (*i.e.*, depletion of the ozone layer). Consequently, a replacement for fluorocarbon-based fire-suppressions systems is being sought. The United States Federal Aviation Administration, for example, is testing alternatives to fluorocarbons in an effort to certify non-toxic, environmentally-friendly, fire-suppression systems for use on aircraft.

U.S. Pat. No. 5,495,893 discloses an apparatus and method to control deflagration of gases. According to the patent, the apparatus includes a dispersing means for dispersing a stream of liquid droplets, a sensing means for detecting a condition that is conducive to combustion/deflagration, and an actuating means that actuates the dispersing means when triggered by the sensing means. The patent states that the dispersing means can be a liquid atomizing device. The liquid, which is preferably water, is supplied to the atomizing device at a pressure in the range of about 50 to 150 psi.

A second fire-suppression apparatus and method for an enclosed space is disclosed in U.S. Pat. No. 6,003,608. According to this patent, a non-combustible gas is introduced into an enclosed space while air is expelled, thereby smothering the fire. The patent also discloses that a fire-extinguishing dry chemical is introduced to the enclosed space.

The systems disclosed in these patents have a variety of shortcomings. Among other drawbacks, the system disclosed in U.S. Pat. No. 5,495,893 uses an atomizing device that requires the use of relatively high-pressure liquid. And the system disclosed in U.S. Pat. No. 6,003,608 lacks a capability for long-duration protection against re-flash fires. Such shortcomings are of particular concern when these systems are to be deployed in aircraft.

Summary of the Invention

The present invention provides an apparatus and method that avoid some of the drawbacks of the prior art.

In some variations, a fire suppression apparatus in accordance with the illustrative embodiment of the present invention includes a supply of gas, a supply of liquid, a control arrangement and a pneumoacoustic atomizer. The gas and liquid are supplied to the pneumoacoustic atomizer under the control of the control arrangement. The pneumoacoustic atomizer generates a mist of liquid that is carried by the gas.

The gas/mist suppresses fire by two mechanisms:

- depriving the fire of oxygen by flooding the area with an inert gas (*e.g.*, nitrogen, *etc.*); and
- cooling the fire through the evaporation of a liquid (*e.g.*, water, *etc.*) that is suspended in the gas.

The supply of gas advantageously includes two sources of gas: bottled and generated. Preferably, two or more bottles or tanks of gas are used. With such an arrangement, the pneumoacoustic atomizer can be fed gas from one of the tanks until it is depleted. The depleted tank is then taken off-line and the atomizer is fed by a second tank. Meanwhile, the gas generator generates gas to re-fill the depleted tank.

The control arrangement includes sensors for detecting a fire condition, and a controller that controls the flow of gas and liquid into the pneumoacoustic atomizer when fire is detected. The control arrangement advantageously supplies water to the pneumoacoustic atomizer at two or more different pressures during operation. Changing pressure in this fashion can increase fire suppression or conserve fire-suppressing liquid, as appropriate. In some variations, the fire-suppressing apparatus includes multiple, independently-controllable pneumoacoustic atomizers for protecting separate areas of a plane, vessel, *etc.*, and for conserving fire-suppressing liquid and gas.

In some embodiments, the pneumoacoustic atomizers used with the fire-suppressing apparatus operate at very low liquid and gas pressures (*i.e.*, liquid: 2 to 10 psi, gas: 40-60 psi). Low pressure operation is particularly advantageous for aviation applications.

Brief Description of the Drawings

FIG. 1 depicts a simplified block diagram of a fire suppression apparatus in accordance with the illustrative embodiment of the present invention.

FIG. 2 depicts further detail of the fire suppression apparatus of FIG. 1

FIG. 3 depicts a first variation of a pneumoacoustic nozzle.

FIG. 4 depicts a second variation of a pneumoacoustic nozzle.

Detailed Description of the Invention

FIG.1 depicts a simplified block diagram of fire-suppression apparatus **100** in accordance with the illustrative embodiment of the present invention. Fire-suppression apparatus **100** is particularly well suited for any of a variety of applications that require non-toxic, long-term, remote fire-suppression capability. For example, fire-suppression apparatus **100** can be used in aircraft and spacecraft, buildings (*e.g.*, warehouses, manufacturing and storage facilities, hospitals, *etc.*), off-shore facilities (*e.g.*, oil platforms, *etc.*) and ships.

As depicted in FIG. 1, fire-suppression apparatus **100** includes gas supply **102**, liquid supply **104**, control arrangement **106**, and one or more pneumoacoustic atomizers **108**, functionally interrelated as shown. As described in more detail later in this specification, when a sensor that is associated with control arrangement **106** senses fire, the control arrangement causes an inert, fire-suppressing gas from gas supply **102** and a fire-suppressing liquid from liquid supply **104** to flow to pneumoacoustic atomizers **108**. Charged with fire-suppressing liquid and gas, pneumoacoustic atomizers **108** produces a mist of liquid droplets suspended in gas.

With regard to fire-suppressing gas, any gas that is substantially inert to the liquid (from liquid supply **104**) can suitably be used; however, the gas is preferably not harmful to humans, at least at moderate concentrations. Suitable gases include, without limitation, nitrogen, carbon dioxide, helium, argon and mixtures thereof. Nitrogen is preferably used.

With regard to fire-suppressing liquid, the liquid should have a heat of vaporization that is sufficient to absorb the heat of a fire. The liquid should have a heat of vaporization that is at least about 500 cal/g. Furthermore, the liquid should have a boiling point that is sufficiently high so that it remains in the liquid phase until vaporized by the heat absorbed from the fire. Based on the foregoing considerations, water, which is cheap, readily available, non-toxic and environmentally friendly, is advantageously used. The liquid can include additives, for any of a number of purposes, as is known to those skilled in the art.

FIG. 2 depicts further detail of illustrative fire-suppression apparatus **100**. As depicted in FIG. 2, gas supply **102** advantageously includes two sources of gas — bottled, in tanks **218** (individually denoted as **218A** and **218B**) and generated, in generator **214**. Tanks **218** serve as accumulators to provide an immediate supply of fire-suppressing gas with an adequate rate of flow. Generator **214** generates gas to refill tanks **218** as they empty.

In the variation depicted in FIG. 2, gas supply **102** includes two tanks **218A** and **218B**. When two (or more) such tanks are used, one tank is used at a time to feed pneumoacoustic atomizers **108**. As the tank feeding pneumoacoustic atomizer **108** depletes, it is switched out in favor of a full tank. Once switched out, the depleted tank is advantageously refilled by generator **214**.

In some variations, gas supply **102** includes only one source of gas; however, for long-term delivery of the fire-suppressing mist, the two sources of gas, as described above, are advantageously used.

Tanks **218** can be of any design, with preference given to light-weight designs for use in aircraft or spacecraft. The capacity of tanks **218** is determined by the requirements of a particular application. In particular, tank capacity will vary as a function of the volume of the space being protected and as a function of the period of time (typically specified) that the system delivers fire-suppressing mist.

In the variation of gas supply **102** depicted in FIG. 2, generator **214** is connected in parallel to tanks **218** by three-way control valves **220** (individually denoted as **220A** and **220B**). Three-way control valves **220** are operable to (1) feed gas from tanks **218** to pneumoacoustic atomizers **108** and (2) admit gas from generator **214** to tanks **218**.

Gas (*e.g.*, nitrogen, *etc.*) generator **214** can be any such device as is commercially available, with a particular selection taking into consideration the weight, power requirements and volumetric flow capability of the unit for a particular application. The generator must be capable of generating gas that has a purity level that is sufficient to suppress combustion. In one variation of gas supply **102**, generator **214** is a nitrogen generator, such as membrane nitrogen generator compressed air pretreatment skid with hydrocarbon removal system and 2200 psig pump (part no. 75700-1-484), commercially available from Whatman Inc. of Tewksbury, Massachusetts. In order to provide generator **214** with air at a sufficiently-high pressure, the inlet of generator **214** is advantageously connected, through control valve **212**, to compressed air bleed **210** from turbine engine **208**, such as is used for propulsion of the aircraft in which fire-suppression system **100** is situated.

It might be necessary to increase the output pressure of generator **214**. To that end, pump **216** is connected downstream of generator **214**. Pump **216** can be, for example, a Haskel pump that is powered by compressed air. The compressed air can be bled, for example, from turbine engine **208**.

Regulator/pressure control valve **222** reduces gas pressure to a pressure that is in the range of about 40 to about 60 psig. For example, in one embodiment, the nitrogen is maintained at 56 psig. Control valve **224** controls the flow of gas to pneumoacoustic atomizers **108**.

As depicted in FIG. 1, fire-suppression apparatus **100** also includes liquid supply **104**. Further detail of a variation of liquid supply **104** is depicted in FIG. 2. For the variation depicted in FIG. 2, liquid supply **104** includes tank **226** for storing a volume of liquid (*e.g.*,water, *etc.*), pressure control valve **228** and supply lines. Tank **226** is advantageously a dedicated supply of liquid for fire suppression apparatus **100**. The size of tank **226** is determined by the design requirements of a particular installation, in known fashion. The liquid in tank **226** can be pressurized in known fashion (*e.g.*, an accumulator, a pump, a connection to compressed air bleed **210**, *etc.*). Control valve **230** controls the flow of liquid into pneumoacoustic atomizers **108**.

As depicted in FIG. 1, fire-suppression apparatus **100** also includes a control arrangement **106** that, on a signal from one of its sensors, opens control valves **224** and **230**. Opening control valve **224** causes gas from gas supply **102** to flow to pneumoacoustic atomizers **108**. Similarly, opening control valve **230** cause liquid from liquid supply **104** to flow to pneumoacoustic atomizer **108**.

In the variation depicted in FIG. 2, control arrangement **106** includes controller **232** and one or more sensors **234**. Controller **232** can be a microprocessor, programmable logic controller, or other digital/analog combination control system. Sensors **234** are positioned in a variety of locations in the monitored location as is appropriate. Any of a variety of different types of sensors **234** that are capable of detecting a condition that is indicative of fire can suitably be used. For example, sensors **234** can be temperature sensors, smoke detectors, infrared sensors, thermal signature sensors, laser sensors and other known devices. Furthermore, sensors **234** can be a combination of different types of sensors (*e.g.*, temperature sensors and smoke detectors).

In operation, sensors **234** monitor their environment for indications of fire. Sensors **234** advantageously send a signal to controller **232** whether or not a fire condition is detected. The purpose of the continuous signal is to provide an indication to controller **232** that sensor **234** is functioning properly.

In the absence of an indication of fire, control valve **212** (controlling compressed air bleed), control valve **224** (controlling gas flow into pneumoacoustic atomizers **108**), control valve **230** (controlling liquid flow into pneumoacoustic atomizers **108**) and control valves **220** (controlling tanks **218**) remain closed.

In the event that a signal from one or more of sensors **234** indicates a fire, controller **232** activates a fire-suppression response. In particular, controller **232** causes control valves **220, 224**

and **230** to open so that liquid and gas is admitted to pneumoacoustic atomizers **108**. It is advantageous to slightly delay the introduction of liquid to pneumoacoustic atomizers **108** for a brief period of time, such as 1 to 2 seconds, until after the gas is introduced. The delay ensures that the desirable dynamic conditions are established at the atomizer. To that end, a delay circuit is incorporated into the logic of controller **232**, or included as a separate device associated with control valve **230**.

In some variations, water is supplied to pneumoacoustic atomizer **108** at two different pressures (at different times). In particular, after an initial fire extinguishing period wherein pneumoacoustic atomizer **108** is operating at a relatively lower liquid pressure, the pressure of the liquid is increased in order to maximize the cooling effect of the mist generated by pneumoacoustic atomizer **108**. After a predetermined amount of time, or after a signal from sensors **234** reaches a predetermined value, the pressure of the liquid can be reduced to the lower pressure. The lower pressure results in a dryer mist being supplied to the protected area. The dryer mist conserves the supply of fire-suppressing liquid and reduces the possibility of the liquid damaging the protected area and/or its contents. In some variations, the lower pressure is about 2 psig and the higher pressure is about 6 psig. The pressure of the liquid supplied to pneumoacoustic atomizer **108** can be varied by adjusting control valve **228**.

A further way to vary the amount of fire suppression provided by fire-suppression apparatus **228** is to change the number of pneumoacoustic atomizers **108** that are operating. For example, after an initial period of operation, the number of activated pneumoacoustic atomizers **108** can be reduced. If the intensity of the fire increases, as indicated by an appropriate signal from sensors **234**, the decommissioned pneumoacoustic atomizers can be reactivated.

For the purpose of providing adequate fire suppression using a minimum amount of fire-suppressing materials, in some variations of the illustrative embodiment, controller **232** operates fire-suppression apparatus **100** in a pulsed mode. In the pulsed mode, fire-suppressing gas-infused mist is delivered until a predetermined condition is satisfied (*e.g.*, a period of time elapses, temperature falls to a certain value, *etc.*) and then stopped. Thereafter, sensors **234** and controller **232** monitor the protected environment for indications of re-flash of the fire. In the event of re-flash, controller **232** re-actuates the fire-suppressing gas/mist. The cycle can be repeated as long as necessary.

The duration of the fire-suppressing gas/mist can be determined as a function of a variety of parameters, including, without limitation, the rate of temperature rise, the rate of temperature reduction and the duration of the time period between detected re-flash events.

In addition to monitoring for indications of fire, the gas pressure in tanks **218** is advantageously monitored. If pressure is low, controller **232** can generate an appropriate alarm.

All active components of fire-suppression apparatus **100** are advantageously supplied with a back-up power source (*e.g.*, battery, *etc.*) and/or are powered by a power source other than the primary electrical system of the vehicle/structure being protected to assure continued operation in the event of a power outage, such as might be caused by a fire.

It is possible to protect a plurality of separate regions with fire-suppression apparatus **100**. For example, multiple cargo areas of a plane or ship can be protected by providing multiple sensors **234** and pneumoacoustic atomizers **108** and placing them in appropriate locations. In such an embodiment, a plurality of gas control valves **224** and water control valves **230** are advantageously used to individually control the flow of gas and the flow of liquid into each of the multiple pneumoacoustic atomizers **108**. Logic or circuitry in controller **232** is connected to receive a signal from each of sensors **234** and can function as a means for detecting a location of a fire as proximate to one or more of pneumoacoustic atomizers **108**. Controller **232** is advantageously capable of actuating only the gas control valve(s) **224** and water control valve(s) **230** for pneumoacoustic atomizer(s) **108** proximate to the fire. In addition to providing multiple discrete areas of coverage, this variation of the illustrative embodiment reduces consumption of fire-suppressing materials by delivering them to only the areas in which they are needed.

Suitable pneumoacoustic atomizers **108** provide water droplets having a size that is in the range of about 50 to 90 microns. Two variations of a suitable pneumoacoustic atomizer **108** are shown in FIGS. 3 and 4.

Pneumoacoustic atomizer **108A**, depicted in FIG. 3, includes rod **336**, inner casing **338**, outer casing **346** and head **352**, interrelated as shown. Defined within or between these elements are gas nozzle **354**, gas feed channel **356**, water nozzle **358**, water feed channel **360** and resonator **364**.

Gas nozzle **354**, which is annular in shape, is defined between the exterior of rod **336** and tapered portion **342** of inner wall **340** of inner casing **338**. Gas is delivered to gas nozzle **354** via annular channel **356** that is defined between the exterior of rod **336** and the non-tapered portion of inner wall **340** of inner casing **338**. Opposing and spaced from gas nozzle **354** is resonator **364**, which is an annular channel that is formed between the exterior of rod **336** and wall **362**. Gas that flows through gas nozzle **354** is braked by resonator **364**.

Liquid nozzle **358**, which is annular in shape, is defined between outer wall **344** of inner casing **338** and tapered portion **350** of inner wall **348** of outer casing **346**. Liquid is delivered to

liquid nozzle **358** via annular channel **360** that is defined between the non-tapered portion of outer wall **344** and the non-tapered portion of inner wall **348** of outer casing **346**.

In operation, gas (*e.g.*, nitrogen, *etc.*) that passes through gas control valve **224** is directed into annular channel **356** that feeds gas nozzle **354**. With sufficient gas pressure, typically at least about 21 psi, gas is discharged from nozzle **354** at the speed of sound. Once discharged, the gas expands and its speed becomes supersonic. The gas is decelerated by resonator **364**, which causes intense acoustic oscillations in atomization zone **366** between gas nozzle **354** and resonator **364**. The gas jet pulses and periodic shock waves occur. The oscillations cause the atomization of liquid (*e.g.*, water, *etc.*) that is supplied through liquid nozzle **358**. A mist of water droplets exits pneumoacoustic atomizer **108A** through annular outlet **370**.

Pneumoacoustic atomizer **108B**, depicted via cross-sectional view in FIG. 4, includes casing **472**, central core **486**, and cowling **506**. Casing **472** has an axially-disposed recess that receives central core **486**. Cowling **506** engages the exterior of casing **472**. Defined within or between the casing, central core and cowling are: axially-disposed channels **498** and **500**, gas chamber **494**, gas nozzle **496**, radial apertures **502**, liquid cavity **504**, liquid inlet **502**, liquid outlet groove **510**, and resonator **512**.

Gas is received by pneumoacoustic atomizer **108** via axially-disposed channel **498** in casing **472** and passes to axially-disposed channel **500** in central core **486**. Radially-disposed apertures **502** in central core **486** enable gas to pass from axially-disposed channel **500** into gas chamber **494**. Gas chamber **494** is defined by walls **474** and **476** of casing **472** and a portion of outer wall **488** of central core **486**. Tapered wall **478**, which depends from wall **476**, and a portion of outer wall **488** of central core **486** define annular-shaped gas nozzle **496**. Gas flows from gas chamber **494** through gas nozzle **496**.

As described in more detail later in this specification, wall **478** should have a taper (measured relative to opposing wall **488**) that is within the range of 60 to 80 degrees. This taper is referred to as the "conicity angle." Furthermore, gas chamber **494** should have a compression factor, μ, at gas nozzle **496** that is in the range of 5 to 30, wherein μ is given by the relation:

[1] $$\mu = (d_k^2 - d_s^2) / (d_n^2 - d_s^2)$$

where: d_k is the diameter of gas chamber **494**;
d_s is the diameter of central core **486**; and
d_n is the diameter of gas nozzle **496**.

Opposing and spaced from gas nozzle **496** is resonator **512**, which is an annular channel that is formed from walls **488**, **489** and **490** in central core **486**. Gas that flows through gas nozzle **496** is braked by resonator **512**.

Liquid is received by pneumoacoustic atomizer **108** via inlet channel **502** that is located at a marginal portion of casing **472**. Liquid flows from inlet channel **502** to annular liquid cavity **504**. Liquid cavity **504** is defined by walls **480** and **482** of casing **472** and a portion of cowling **506**. Depending from liquid cavity **504** is a narrow, annular liquid outlet groove **510** that is defined by wall **484** of casing **472** and wall **508** of cowling **506**. Unlike the liquid nozzles of other pneumoacoustic atomizers, which are defined by converging walls, the walls that define annular groove **510** are parallel.

It is known that there exists some threshold sound pressure that corresponds to the beginning of the dispersion of liquid during pneumoacoustic atomization. This threshold depends upon a variety of factors, including the surface tension of the liquid being atomized, the shape of the initial liquid jet, and the presence of a gas flow. In accordance with the illustrative embodiment, a sound pressure level required for efficient dispersion of water is in the range of 160 to 170 dB, which corresponds to a sound intensity in the atomization zone of about 1-10 W/cm.

The atomization process depends not only on the sound pressure level, but also on the frequency of the sound. In particular, the size of the resulting liquid droplets decreases with increasing frequency of acoustic waves. It has been found that to obtain water droplets in the size range of 50 to 90 microns, frequency must be within the range of about 16 to 20 kHz. The frequency of acoustic oscillations is a function of the height ***H*** of the resonator and the width ***W*** of the gap at the mouth of the gas nozzle (hereinafter "δ").

It is known that for a near-wall ring jet, such as occurs in the configuration of pneumoacoustic atomizers **108A** and **108B**, the unsteady modes that are formed as a result of the deceleration caused by an empty resonator are realized at Strouhal numbers, Sh, that are close to the quarter-wavelength resonance. That is:

[2] $\mathrm{Sh} = \Delta / \lambda = 0.21$ to 0.23

where: Δ is cell length of the supersonic jet; and

λ is wavelength and $\lambda = c/f$ (c is the speed of sound in the gas and f is the generation frequency).

The cell length Δ is proportional to the width of the nozzle gap δ and also depends upon both the pressure of the supplied gas (usually within 2.5 - 5 atmospheres) and the transverse curvature of the out-flowing jet. The curvature is determined by the ratio between the diameter d_s of rod **340** (or central core **486**) and the diameter d_n of the gas nozzle **354** or **496**. For use in fire-suppression apparatus **100**, the curvature parameter R should be within the range of about 0.8 to about 0.9 wherein R is given by the expression:

[3] $R = d_s / d_n$

Given this range for the value of the curvature parameter R, the Strouhal numbers are obtained for $\delta = (0.03 - 0.055)\ \lambda$, and the required droplet dimensions (*i.e.*, 50-90 microns) can be achieved by using a resonator having depth that is determined by the relation:

[4] $H = (3 \leftrightarrow 5)\delta$

since the necessary sound pressure levels of 160-170 dB can be obtained only for these values of H.

The instability of the out-flowing gas is determined by the occurrence of the transverse component of the speed of the gas. It has been found that this instability is related to the epure of speed (*i.e.*, velocity profile) at the cross-section of the nozzle. The shear is related to conicity angle of the nozzle. During abrupt changes in flow (*i.e.*, a large conicity angle), the instability is increased because of a point of flex (*e.g.*, an inflection point, *etc.*) in the epure of speed. Thus, to increase the intensity of the shock waves, it is advantageous to use a nozzle having a conicity angle of between about 60 to 80 degrees. This feature is included in the pneumoacoustic atomizer **108B**, which is depicted in FIG. 4.

Pneumoacoustic atomizer **108B** having a nozzle conicity angle in the range of 60-80 degrees showed an increase in efficiency of 18 to 26 percent over pneumoacoustic atomizer **108A**. The intensity of the shock waves in the atomization zone increase by 4 dB.

A second advantage of pneumoacoustic atomizer **108B** is that, relative to atomizer **108A** and relative to prior art pneumoacoustic atomizers, it is constructed of fewer parts. In particular, pneumoacoustic atomizer **108B** is constructed of only three parts: casing **472**, central core **486** and cowling **506**. This reduces cost and improves reliability.

It is to be understood that the above-described embodiments are merely illustrative of the invention and that many variations may be devised by those skilled in the art without departing from the scope of the invention and from the principles disclosed herein. It is therefore intended that such variations be included within the scope of the following claims and their equivalents.

We claim:

1. An apparatus comprising a pneumoacoustic atomizer, said pneumoacoustic atomizer having:

an annular gas chamber that is defined, at least in part, within a casing; and

an annular nozzle that connects to said annular gas chamber for the passage of gas therethrough, wherein said annular nozzle has a tapered side wall, and wherein said tapered side wall has a convergence angle that is in the range of 60 to 80 degrees relative to an axis of spray.

2. The apparatus of claim 1 wherein said pneumoacoustic atomizer further comprises:

an axially-disposed channel that is defined within said casing; and

a plurality of radially-disposed apertures that connect said channel with said annular gas chamber for the passage of gas therethrough.

3. The apparatus of claim 1 wherein said pneumoacoustic atomizer further comprises:

an annular liquid cavity that is defined, at least in part, within said casing;

an inlet in said casing that connects with said annular liquid cavity for the passage of liquid therethrough; and

an annular groove that connects to said annular liquid cavity for the passage of liquid therethrough, wherein said annular groove has side walls that are parallel.

4. The apparatus of claim 3 wherein a pressure of said liquid within said annular liquid cavity is less than about 10 psig.

5. The apparatus of claim 1 wherein said pneumoacoustic atomizer further comprises an annular channel that is spaced from and opposes said annular nozzle, wherein said annular channel defines a resonator.

6. The apparatus of claim 5 wherein said pneumoacoustic atomizer further comprises a core that is received by a recess within said casing, wherein said core and said casing are axially aligned, and wherein said annular channel is defined with said core.

7. The apparatus of claim 1 wherein said pneumoacoustic atomizer further comprises a core that is received by a recess within said casing, wherein said core and said casing are axially aligned, and wherein said annular gas chamber has a compression factor, μ, at the nozzle, that is in a range of about 5 to 30.

8. The apparatus of claim 1 wherein said pneumoacoustic atomizer further comprises a core that is received by a recess within said casing, wherein said core and said casing are axially aligned, and wherein:

said annular nozzle has an inner wall and an outer wall;

said tapered side wall is said outer wall; and

an exterior of said core is said inner wall.

9. The apparatus of claim 7 wherein:

an axially-disposed channel is defined in said core;

said axially-disposed channel in said core connects to said axially-disposed channel in said casing for the passage of gas therethrough; and

said radially-disposed apertures are defined in said core.

10. The apparatus of claim 1 wherein said pneumoacoustic atomizer consists of three parts, wherein said three parts are said casing, a core that is received by a recess within said casing, and a cowling that abuts a perimeter of said casing.

11. The apparatus of claim 1 further comprising:

a supply of gas that is connected to said pneumoacoustic atomizer, wherein said supply of gas comprises a bottle containing said gas and a gas generator that generates said gas;

a supply of water that is connected to said pneumoacoustic atomizer;

an arrangement for controlling said supply of gas and said supply of water to said pneumoacoustic atomizer; and

a connection between said generator and said bottle for delivering gas to said bottle.

12. The apparatus of claim 11 further comprising a pump that is connected between said gas generator and said bottle, wherein said pump is further connected to a turbine engine.

13. The apparatus of claim 11 wherein said connection comprises a three-way valve that is connected to an inlet of said pneumoacoustic atomizer, to an outlet of said gas generator, and to said bottle.

14. The apparatus of claim 11 wherein said gas generator is connected to a compressed air bleed from a turbine engine.

15. The apparatus of claim 11 wherein said arrangement comprises:

a temperature sensor that generates a temperature signal;

a gas control valve that is connected between said supply of gas and said pneumoacoustic atomizer;

a water control valve that is connected between said supply of water and said pneumoacoustic atomizer;

a controller, wherein, said controller receives said temperature signal from said temperature sensor and controls said gas control valve and said water control valve responsive to said temperature signal; and

a delay circuit that is connected to said water control valve and that delays opening of said water control valve for a period of time.

16. The apparatus of claim 11 wherein a pressure of said supply of water is less than 10 psig.

17. An apparatus comprising:

a supply of nitrogen comprising bottled nitrogen and a nitrogen generator, wherein said nitrogen generator is supplied with compressed air from a compressed air bleed from a turbine engine;

a supply of water;

a pneumoacoustic atomizer that is connected to said supply of nitrogen via a nitrogen control valve, and that is connected to said to said supply of water via a water control valve, wherein said pneumoacoustic atomizer generates a flow of nitrogen containing a mist of water droplets when supplied with nitrogen from said supply of nitrogen and with water from said supply of water having a predetermined size range;

a fire detector that generates a signal in response to a fire;

a controller that receives said signal from said fire detector, wherein said controller controls operation of said nitrogen control valve and said water control valve responsive to said signal; and

a delay circuit that delays the opening of said water control valve.

18. The apparatus of claim 17 wherein said pneumoacoustic atomizer consists of three parts, including:

a casing, wherein said casing has a substantially annular shape that is defined by an inner wall and an outer wall;

a central core, wherein said central core is received by said casing and axially aligned therewith; and

a cowling, wherein said cowling abuts said outer wall of said casing.

19. The apparatus of claim 18 wherein a first portion of said inner wall of said casing defines a first axially-disposed channel.

20. The apparatus of claim 18 wherein said pneumoacoustic atomizer comprises a gas nozzle, wherein said gas nozzle is a first annular channel that has:

an outer wall that is defined by a second portion of said inner wall of said casing; and

an inner wall that is defined by a portion of an exterior wall of said central casing.

21. The apparatus of claim 20 wherein said outer wall has a convergence angle that is in the range of 60 to 80 degrees relative to an axis of spray.

22. The apparatus of claim 19 wherein said pneumoacoustic atomizer further comprises a water nozzle, wherein:

said water nozzle is a second annular channel that has:

an inner wall that is defined by a portion of said outer wall of said casing; and

an outer wall that is defined by a portion of said cowling;

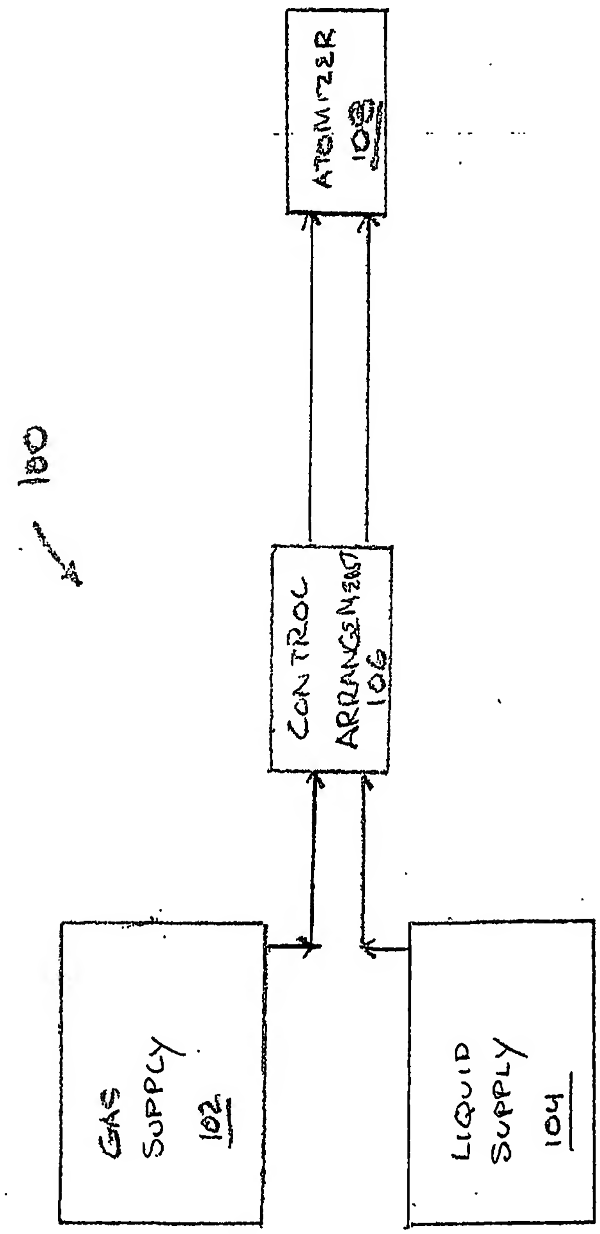
said inner wall and said outer wall are parallel; and

said water nozzle is disposed in concentric relation with said gas nozzle.

23. The apparatus of claim 19 wherein said central core has a second axially-disposed channel that connects with said first axially-disposed channel in said casing for the passage of gas, and wherein pneumoacoustic atomizer further comprises a plurality of radially-disposed apertures, wherein:

said radially-disposed apertures are defined within said central core; and

said radially-disposed apertures enable the passage of gas from said second axially-disposed channel in said central core to said gas nozzle.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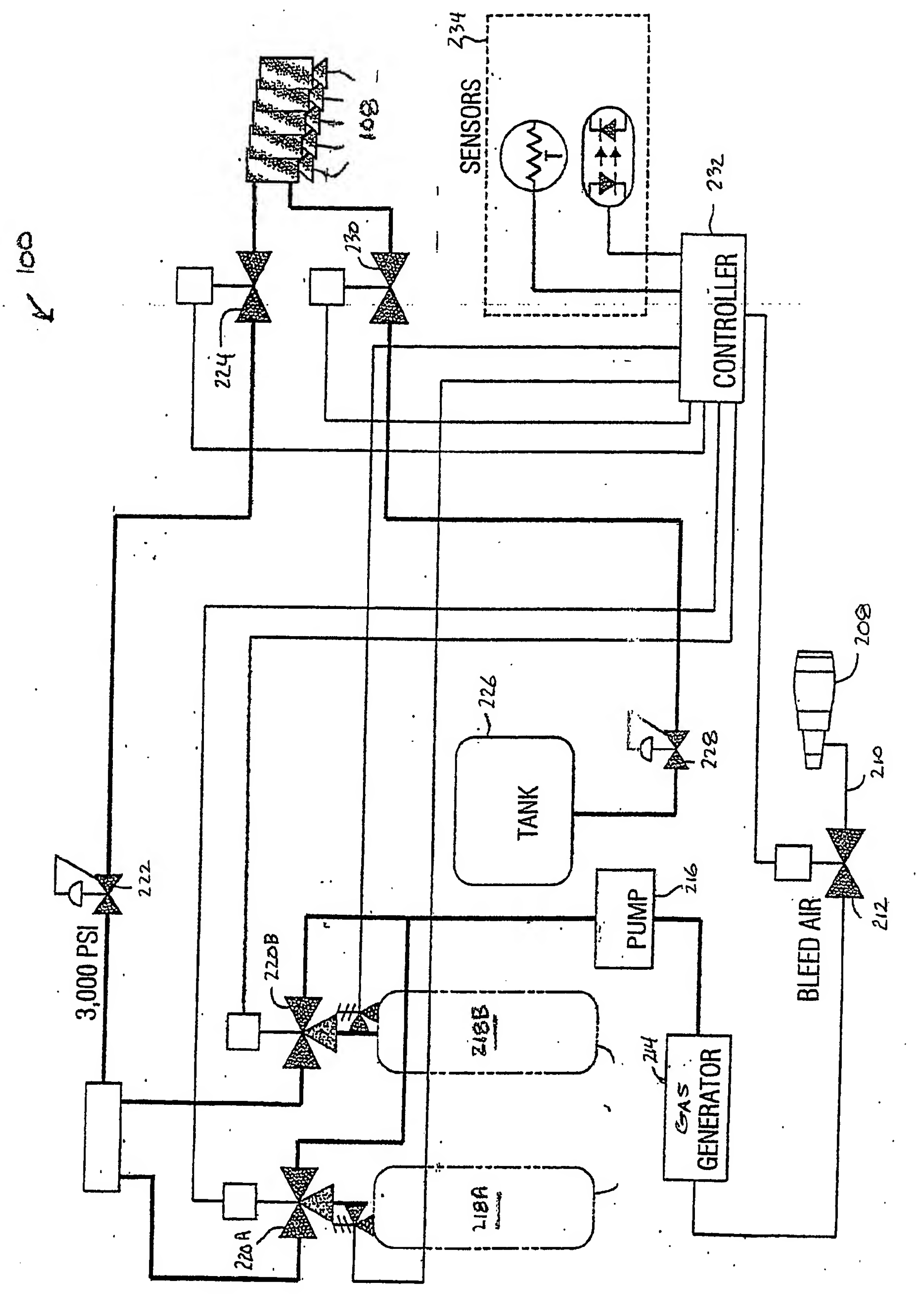
LIQUID SUPPLY 104
CONTROL ARRANGEMENT 106
ATOMIZER 108

FIG. 1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TANK
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PUMP
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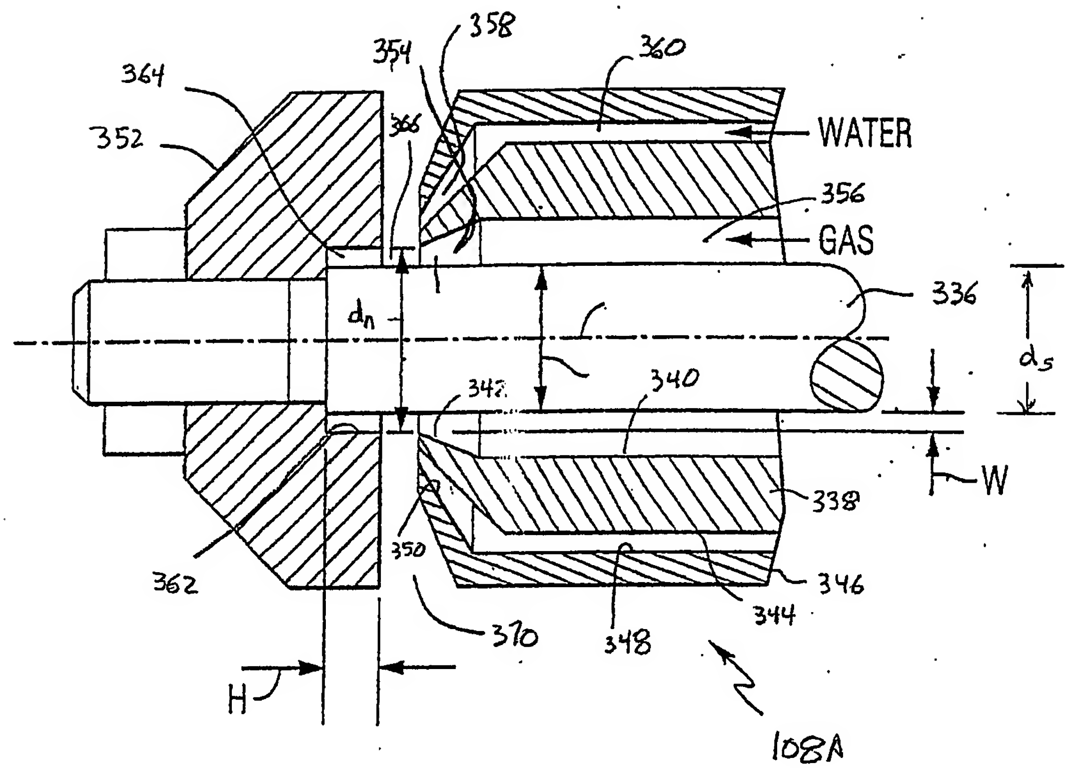
BLEED AIR
220B
218B
214
GAS GENERATOR
218A
220A

FIG. 2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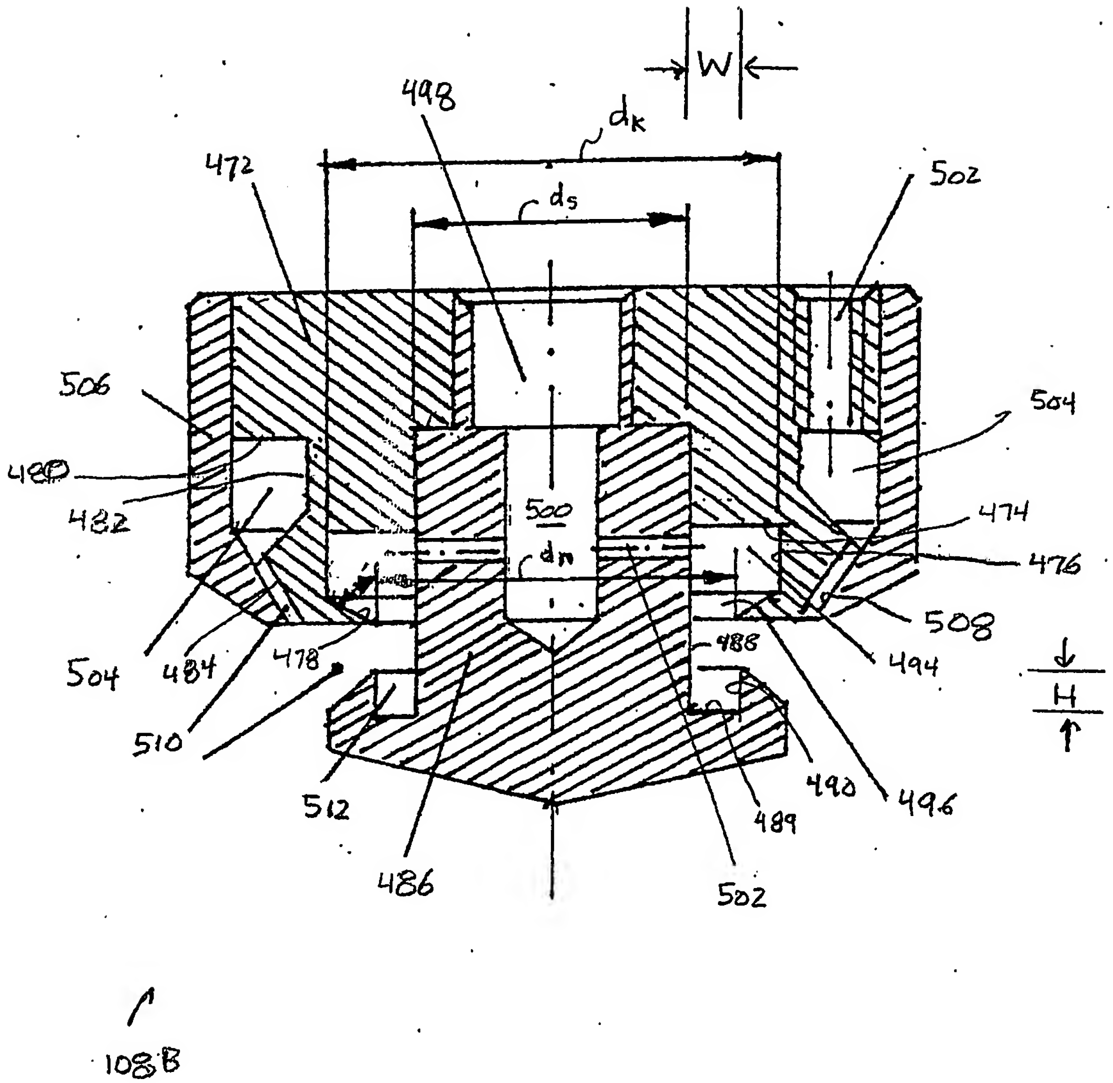
H
108A

FIG. 3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478
510
H
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496
512
489
486
502
108B

FIG. 4